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Implementation and Testing of Overset Grid Capability for Supersonic Flows

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Abstract

The paper discusses the overset grid methodology implementation and its testing at transonic and supersonic Mach numbers. The motivation is to make the grid generation process easier and less time consuming, without hampering the accuracy of simulation. In the near-body region body fitted curvilinear structured grids and in the off-body region Cartesian grids were used, which gives large scope for automation in the off-body grid generation. Donor cells for fringe cells have been searched by using the Barycentric coordinates. The interpolation of conservative variables from donor cells to fringe cells has been carried out through area weighted averaging. It is observed that this interpolation technique is preserving the conservation at the discontinuities like shocks, without causing any spurious oscillations. Efficient polygon clipping algorithm has been used for calculating the various area fractions. The module was tested for steady state Euler & viscous flows and unsteady state moving shock problems. In all the cases shocks crossed the overset boundary without any distortion.

Key words: Overset Grid, Conservative Interpolation, Polygon Clipping Algorithm

1 Introduction

In CFD analysis, grid generation phase consumes not only considerable amount of time but also becomes very difficult as the configurations in most of the real cases have complex shapes or multi-bodies. These difficulties can be alleviated by decomposing the total computational domain into various regions (called as blocks) with some overlap between them in such a way that grid generation in each individual block becomes independent and easy. This is called as Chimera or Overset grid technique, which gives lot of flexibility for grid generation in each block. The technique is extremely useful when there is relative movement between various bodies in multi-body configurations like helicopter rotors, store separation, control surface movement, etc. The stretching or distortion of cells occur due to relative movement in continuous grids can be avoided by just moving the block of the grid attached along with the body in the overset grids. In the high gradient areas of computational domain, local grid adaptation can be implemented very easily in this type of grid methodology. The penalty, which we have to pay for the advantages like these, is dealing with the artificial boundaries created at the overlaps. In each iteration or after few predefined iterations, we have to provide the boundary information at those artificial boundaries through interpolation from the overlapped region of adjacent block.

The overset grid technology was developed 30 years back by Steger et al [1] and went through so many improvements since then. The chimera technique development was the result of motivation of Steger, to simulate the problems involving relative motion between various components, like store separation [2]. Later the unsteady three-dimensional viscous flow simulations were carried out on store separations by Steger et al [3] and relative motion in multiple body configurations by Meakin et al [4]. Chimera technique has been used widely for simulation of helicopter rotors like Schwarz et al [5].

After the grid generation, inter-connectivity information between various blocks in the computational domain has to be developed first, which includes a process (called as blanking or hole cutting) of blanking the grid points (called as hole points) of one block, which are with in the wall of another block. There are wide range of hole cutting techniques available, like by using the surface definition due to Wang et al [6] , by using object X-ray technique due to Meakin [7], direct cut approach due to Noack [8], etc.

The adjacent grid points of the hole points, which are out of wall, and other boundary grid points of a block in the overlapped region, are called as fringe points, where the field information has to be interpolated. Hence locating the fringe points of each block is the first step of interpolation and the second step is locating their respective donor cells. There are 'geometric preconditioner algorithms' or stencil walk algorithm [9], for the purpose of locating the donor cells. The third part of interpolation is updating the field values of fringe points with interpolation algorithms. Wang [10] proposed a fully conservative interpolation algorithm for overlapped grids. There are various other algorithms available in literature for interpolation.

The aim of the present work is to implement and test the overset grid capability module in the 2D version of the in-house code MB-EURANIUM. Three different sets of studies have been carried out. First steady state Euler flow past NACA 0012 aerofoil and 16° compression ramp are used to test the module. Next, the module is tested for viscous flow past compression ramp and finally for a moving shock over the compression ramp. In all these cases grid sizes used are similar to the various previous studies carried out on these geometries with the same solver and hence grid independence studies were avoided.

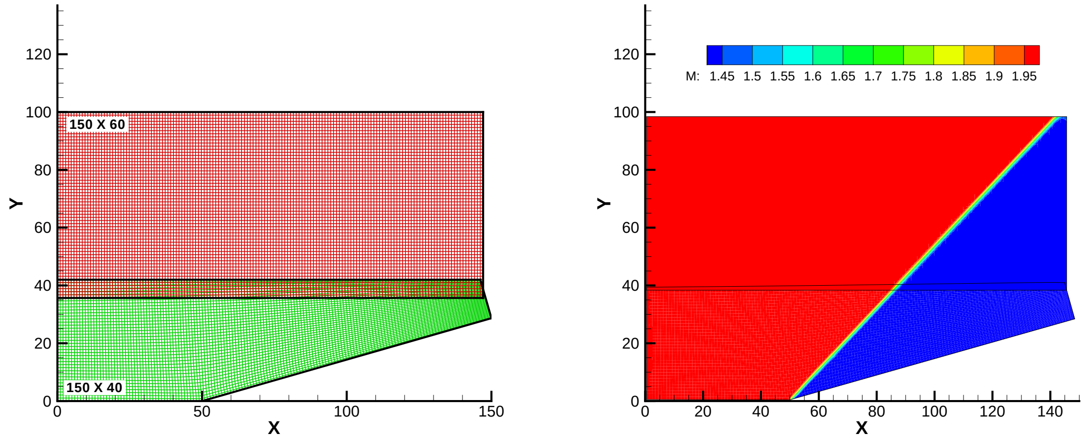
2 Overset Grid Module

Body fitted curvilinear structured grids in the near-body blocks and Cartesian grids in the off-body blocks have been used. The overset grid preprocessing consists of two steps, hole cutting and interpolation. The hole cutting, on the generated overset grids, has been carried out with manual intervention in the present stage of implementation and will be fully automated in the future. The second step of overset grid preprocessing, interpolation, consists of three stages. For the requirement of second order accurate solver, two rows of boundary cells from the overlapped region have been taken as fringe cells, which completes first stage of interpolation. The second stage -donor cell search has been carried out by using the barycentric coordinates.

The third stage is actual interpolation algorithm. In the present study the time-flux conservation approach given by Rai [11] and Thomas et al [12] is used with area weighted interpolation [13, 14]. The various area fractions required in the interpolation are obtained using the polygon clipping algorithm of Hua & Tokuta [15].

3 Flow solver Numerical Approach

A brief outline of the numerical approach followed to solve the equations is presented here. It employs a Total Variation Diminishing (TVD) formulation based on Monotone Upwind Scheme for Conservation Laws (MUSCL) within the frame work of cell centered finite volume approach and generalized body-fitted coordinates to discretize the Euler terms[16, 17]. The Euler terms are discretized using the



(a) Euler grid

(b) Mach contours

Figure 1: Euler grid and Mach contours on 16° compression ramp

AUSMDV [18] flux-splitting method. Chakravarthy-Osher limiter is used. The viscous terms are central differenced. The matrix-free LU-SSOR implicit time stepping scheme [19, 20] is used for the solution.

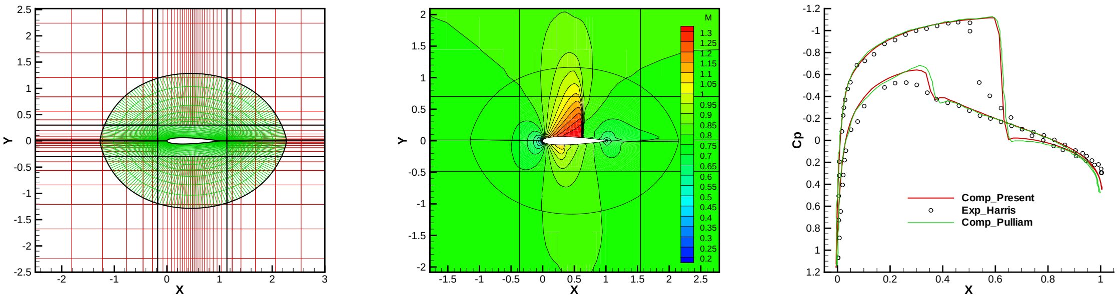
4 Results

4.1 Euler Analysis

Figure 1(a) shows the grid on the 16° compression corner. The domain has been divided into two blocks, with one block in the near-body and another in the off-body region. The near-body block consists of body fitted curvilinear grids with 150 cells along the wall and 40 cells normal to the wall. The off-body block consists of uniform Cartesian grid with 150 cells in the direction parallel to wall and 60 cells in the normal direction. The simulations are done for a free stream Mach number of 2. Figure 1(b) shows the Mach contours. It can be noted that shock has passed the overlap region just like in continuous grid without any spurious oscillations. Table 1 shows the comparison of computed results of shock angle, shock down stream Mach number and down stream to upstream ratios of other quantities against the analytical results from oblique shock theory.

Table 1: 16° compression ramp results

Parameter	$M_\infty = 2$		$M_\infty = 4$	
	Analytical	Computed	Analytical	Computed
Shock angle	46.7306	46.4389	28.0979	28.1117
M_2	1.4034	1.4023	2.8570	2.8570
P_2/P_1	2.3075	2.3032	3.9740	3.9615
ρ_2/ρ_1	1.7869	1.7835	2.4908	2.4766
T_2/T_1	1.2913	1.2098	1.5954	1.4065



(a) Grid (b) Mach contours (c) C_p distribution

Figure 2: Grid, Mach contours and C_p distribution around NACA 0012 aerofoil

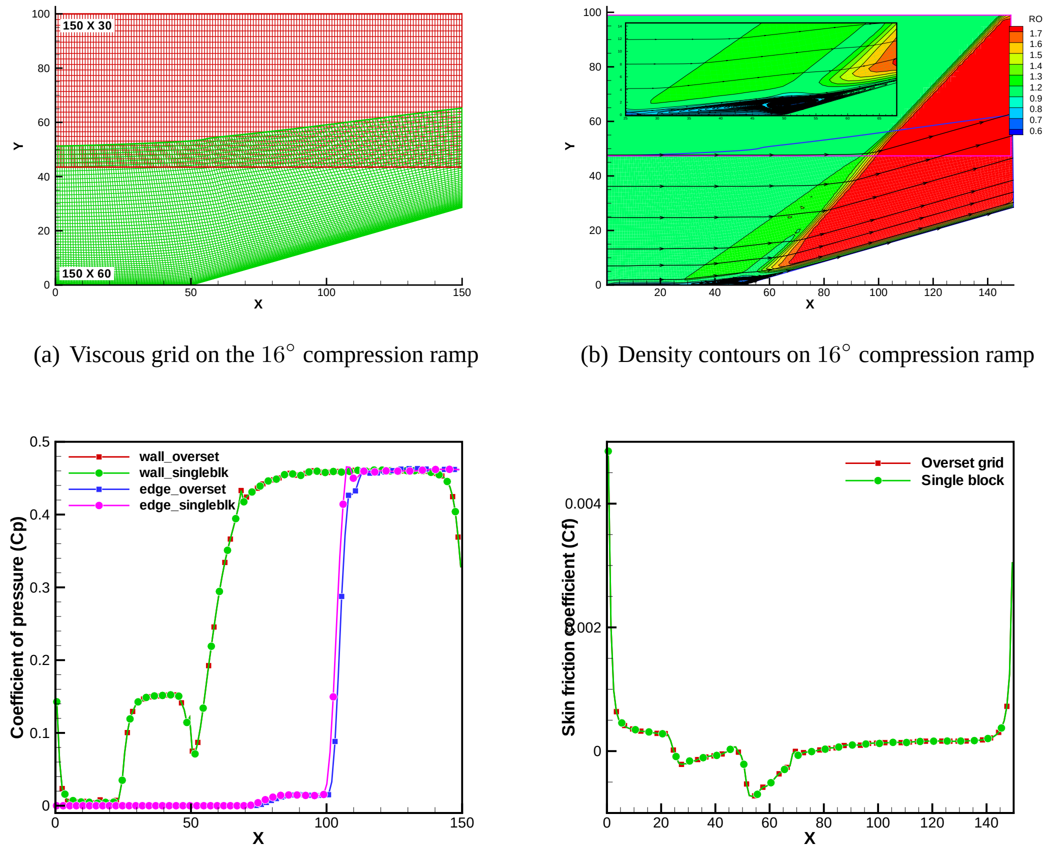
Figure 2(a) shows the grid around the NACA 0012 aerofoil. The near-body block consists of structured O-grid with 200 cells along the aerofoil and 18 cells normal to it. The off-body block consists of Cartesian grid with 54 cells in the direction parallel to aerofoil and 44 cells in the normal direction. The hole cutting has been carried out with manual intervention and needs to be automated. The simulations are done for a free stream Mach number of 0.8 and angle of attack of $1.25°$. Figure 2(b) shows the Mach contours around the aerofoil. Figure 2(c) shows the variation of computed coefficient of pressure along the surface of the aerofoil against the experimental results of Harris [21] and the computed Euler results of Pulliam [22]. Comparison shows that there is very good agreement between both computed results, where as experimental results are deviating due to viscous effects.

4.2 N-S Analysis

For viscous flow analysis on $16°$ compression ramp, the grid shown in Figure 3(a) was used with normal to wall grid spacing of 1 X 10^{-6} that of the height of the channel. The simulations are done for a free stream Mach number of 2 and Reynolds number of 22000 with an adiabatic wall condition. Figure 3(b) shows the density contours on the ramp with a zoomed view of the corner region, which shows the recirculation bubble clearly. Separation shock can be seen ahead of the separation zone which passes through the interface and joins the corner shock. A single block computation was also carried out on a grid, in which the near-body grid extended upto far-field same as that of overset case. Figure 3(c) shows the comparison between coefficient of pressure of overset case and single block case at the wall and at the overset boundary edge of near-body block. The exact match at the wall speaks about negligible influence of using overset grid instead of single block grid. There is minor variation at the edge of near-body block, which can be attributed to interpolation error. An exact match of skin friction coefficient of overset case with single block case is obtained, which is shown in figure 3(d). In the recirculation region, there is a very small contra-rotating bubble just before the corner, which makes the skin friction coefficient positive for very little length.

4.3 Moving Shock

The grid used is similar to that in the Euler flow except the front part, which was extended in the -ve X-direction upto -50. The near-body block had 50 cells and far-body block had 40 cells along the wall



(a) Viscous grid on the 16° compression ramp

(b) Density contours on 16° compression ramp

(c) 16° compression ramp: C_p distribution

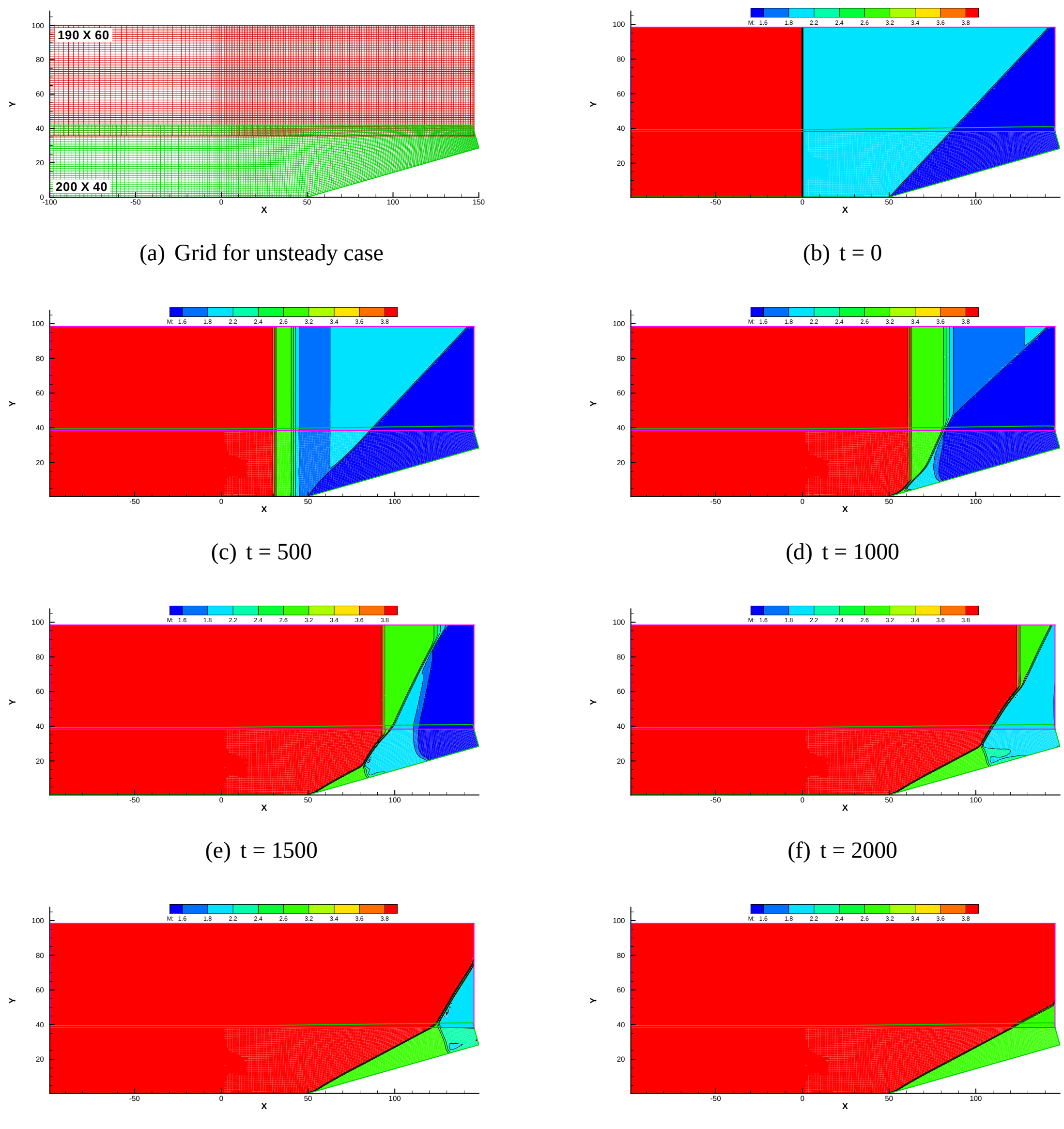
(d) 16° compression ramp: C_f distribution

Figure 3: Grid, Density contours, C_p and C_f distribution on 16° compression ramp

in this extended region as shown in figure 4(a). The initial solution over the ramp corresponds to a free-stream Mach number of 2. A new inlet condition is then prescribed corresponding to a Mach number of 4 through the extended region. This initial solution is shown in figure 4(b). This leads to a moving shock into the domain. The oblique shock angle changes from Mach 2 to Mach 4 as the Mach 4 normal shock wave moves over the ramp. This unsteady interaction between oblique shock and normal shock can be seen through figure 4(c) to (g). Figure 4(h) shows the final Mach 4 oblique shock. The presence of overset grid boundary doesn't create any obstruction either for the normal shock movement or for the various unsteady shock interactions. Table 1 shows the comparison of various computed results against the analytical results from oblique shock theory for a free-stream number of 4.

5 Conclusion

Overset grid capability has been implemented and tested in the 2D version of the in-house code MB-EURANIUM. Body fitted curvilinear structured grids in the near-body and Cartesian grids in the off-body were used. In the present stage hole cutting has been carried out with manual intervention and will



(a) Grid for unsteady case

(b) t = 0

(c) t = 500

(d) t = 1000

(e) t = 1500

(f) t = 2000

(g) t = 2500

(h) t = 3000

Figure 4: Grid and unsteady Mach contours on 16° compression ramp at various time levels

be automated in the future. Two Euler flow, one viscous flow and one unsteady moving shock simulations were carried out. In all these simulations the presence of overset boundary doesn't create any disturbance to flow and behaved as if the grid was continuous there.

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